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BALLISTIC TESTS OF 2024-T4 AND 7075-T6 ALUMINUM ALLOYS (U)

By

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July 1957

OOO Project No. TB4-005
DA Project No. 5B93-32-005

PITMAN-DUNN LABORATORIES GROUP
FRANKFORD ARSENAL
Philadelphia, Pa.

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OBJECT

To systematically evaluate the ballistic resistance of 2024-T4 and 7075-T6 aluminum alloy plates when subjected to small arms projectile firings.

SUMMARY

Aluminum alloys 2024-T4 and 7075-T6, in 1/8, 1/4, 1/2, 3/4, 1, and 1 1/2 inch thicknesses were tested for ballistic resistance to penetration and spalling at plate obliquities of 0, 30, 45, 55, 60, 65, 70, and 80 degrees. Caliber .50 AP M2, 20 mm AP M95, and 20 mm AP T33 projectiles were used in this investigation.

For armor purposes, the 2024-T4 alloy is generally superior to the 7075-T6 alloy with respect to ballistic protection, and spalls considerably less. For defeating aluminum alloys of these types, the 20 mm AP T33 projectile is generally superior to the 20 mm AP M95 projectile.

AUTHORIZATION

Sub RAD ORDTB 2-1064, 22 December 1953.

INTRODUCTION

In the future it is quite likely that aluminum alloys will be used instead of steel for armor purposes on various types of lightly armored military vehicles. It is known that some aluminum alloys exposed at intermediate and high obliquities provide better ballistic protection against exploded shell fragments and small caliber projectile firings than steel armor of equivalent weight.

Results of this work are reviewed in Reference 1.* Ballistic and mechanical tests conducted at this arsenal(2) and at Case Institute of Technology,(3,4) respectively, have shown that resistance to penetration for 1/2 inch thick plate is linearly proportional to hardness, regardless of alloy composition, toughness, ductility, or any other mechanical property evaluated, up to approximately 120 Bhn. In hardness ranges exceeding 120 Bhn, the ballistic limit-hardness relation was no longer only linear, but became dependent upon toughness also.

Substitution of aluminum alloys which afford the same ballistic protection as steel would also provide a considerable weight saving. This is a very important factor in air-borne vehicle considerations.

The frontal armor of most military vehicles is exposed at obliquities of attack greater than 45 degrees. Military aircraft is constructed mainly of aluminum alloys and, in combat, is also exposed at very high obliquity conditions of impact. In the past other military installations have investigated the ballistic resistance of different aluminum alloys for various target conditions which did not include very high obliquities. This program, therefore, was planned and conducted to systematically investigate the majority of potential targets (armored and aircraft) which might be subjected to small caliber projectile firings. It included thicknesses varying from 1/8 to 1 1/2 inches, and obliquities ranging from 0 to 80 degrees.

MATERIALS AND METHODS

Plate

Commercial alloys 2024-T4 and 7075-T6, in thicknesses of 1/8, 1/4, 1/2, 3/4, 1, and 1 1/2 inches, were used in this investigation. These alloys were chosen because they were considered to offer more resistance

*See attached REFERENCES

to projectile penetration than some of the other commercially available ones. Furthermore, some ballistic data already existed for these alloys. (Some of the ballistic and mechanical properties of alloys 2024-T4 and 7075-T6 are discussed in Reference 1.)

Ob:

Projectiles

Caliber .50 AP M2, 20 mm AP M95, and 20 mm AP T33 projectiles were used in these tests. The first two types are standard rounds; the third type is a scale model of the 90 mm AP T33 shot. The latter round was chosen since extensive tests against steel armor have been made at the 20 mm scale at this arsenal and, at Watertown Arsenal, at the caliber .40 scale.

RESULTS AND DISCUSSION

The test conditions and a summary of the ballistic results are presented in Table I. The data are presented graphically in Figures 1 through 5. In order to compare alloy resistance to penetration of projectiles of two different weights and diameters, the specific limit energy,* rather than the ballistic limit, was used in these performance graphs. In Figures 1, 2, and 3 the protection ballistic limit (PBL)** is also indicated at the right side of the graph. Since data for projectiles of different weights are plotted in Figures 4 and 5, no scale for the PBL is given.

*The specific limit energy is the kinetic energy of the projectile divided by the cube of its diameter, or

$$\frac{WV_L^2}{d^3}$$

where

W = weight of the projectile in pounds
V_L = limit velocity of the plate in feet per second
d = diameter of the projectile in inches.

**A protection-complete penetration is obtained whenever a fragment or fragments of either the impacting projectile or the plate are ejected from the rear of the plate with sufficient energy to perforate a thin, mild steel plate (about 0.020 in.) or equivalent screen placed parallel to and approximately six inches rearward of the plate.

Table I. Summary of Ballistic Results for 2024-T4 and 7075-T6 Aluminum Alloys

Obliquity (°)	Projectile	Alloy	1/8 in.	1/4 in.	1/2 in.	3/4 in.	1 in.	1 1/2 in.
			Protection Ballistic Limits (fps)					
0	T33							
		2024-T4	-	-	-	-	1123	1670
		7075-T6	-	-	-	-	1030	1420
	M95							
		2024-T4	-	-	-	-	1310	1680
		7075-T6	-	-	-	-	970	1510
	M2							
		2024-T4	-	-	-	1365	1670	2030
		7075-T6	-	-	-	1260	1695	2075
30	T33							
		2024-T4	-	-	-	-	1390	1905
		7075-T6	-	-	-	-	1285	1875
	M95							
		2024-T4	-	-	-	-	1455	1920
		7075-T6	-	-	-	-	1415	1965
	M2							
		2024-T4	-	-	-	1350	1660	2225
		7075-T6	-	-	-	1420	1820	2385
45	T33							
		2024-T4	-	-	-	1500	1860	2360
		7075-T6	-	-	-	1390	1795	2460
	M95							
		2024-T4	-	-	-	1510	1950	2475
		7075-T6	-	-	-	1410	1935	2535
	M2							
		2024-T4	-	-	1505	1735	2285	3080
		7075-T6	-	-	1535	2160	2530	3200
55	T33							
		2024-T4	-	-	-	-	-	2990
		7075-T6	-	-	-	-	-	3040
	M95							
		2024-T4	-	-	-	-	-	3010
		7075-T6	-	-	-	-	-	3255
	M2							
		2024-T4	-	-	1815	2460	3005	4050
		7075-T6	-	-	2030	2680	3400	>4190

Table I. Summary of Ballistic Results for 2024-T4 and 7075-T6 Aluminum Alloys (Cont'd)

Obliquity (°)	Projectile	Alloy	Protection Ballistic Limits (fps) 1/8 in.	1/4 in.	1/2 in.	3/4 in.	1 in.	1 1/2 in.
60	T33							
		2024-T4	-	-	1450	1960	2730	3555
		7075-T6	-	-	1125	1760	2400	3510
	M95							
		2024-T4	-	-	1550	1845	2140	3465
		7075-T6	-	-	1230	1720	2325	3400
	M2							
		2024-T4	1000	1475	2230	2945	3620	-
		7075-T6	895	1330	2220	2900	3750	-
65	T33							
		2024-T4	-	-	1660	2260	3090	-
		7075-T6	-	-	1120	1930	2720	-
	M95							
		2024-T4	-	-	1705	1945	2600	-
		7075-T6	-	-	1380	1885	2580	-
70	T33							
		2024-T4	-	-	1905	2745	3580	-
		7075-T6	-	-	1375	2220	3015	-
	M95							
		2024-T4	-	-	1955	2200	2840	-
		7075-T6	-	-	1455	2405	3175	-
	M2							
		2024-T4	1130	1825	3150	-	-	-
		7075-T6	1090	1715	2870	-	-	-
80	M2							
		2024-T4	1575	2710	>4200	-	-	-
		7075-T6	1430	2650	>4450	-	-	-

2024-T4 and 7075-T6 Alloys vs 20 mm AP M95 Projectiles

Figure 1 shows the behavior of the AP M95 projectiles as a function of obliquity for various plate thicknesses. For the majority of conditions, the 2024-T4 plate is somewhat superior to the 7075-T6 plate in defeating the M95 shot. Against thin plate, i. e., 1/2 inch, this superiority is as much as 500 fps, or 82 per cent, on an energy basis. The exceptions are mostly for thick plate at high obliquity, such as 1-inch plate at 60° and 70° obliquities.

2024-T4 and 7075-T6 Alloys
vs
20 mm AP T33 Projectiles

As shown in Figure 2, the 2024-T4 plate is superior to the 7075-T6 plate for stopping the T33 shot under all conditions of attack investigated, except for 1 1/2-inch plate at 45° and 55° obliquities. Under these conditions the two plates are approximately equivalent. The superiority of the 2024-T4 alloy is greater for the thin plates. Against the 1/2-inch plate at 65° obliquity, 120 per cent more energy and an additional 540 fps are required to defeat the 2024-T4 plate than the 7075-T6 plate. For the undermatching* targets, the 7075-T6 plate spalls considerably, and complete penetrations often occur without the projectile perforating the plate. This is discussed more completely in the section entitled "Spalling."

2024-T4 and 7075-T6 Alloys
vs
Caliber .50 AP M2 Projectiles

Against the caliber .50 AP M2 projectiles (Figure 3), the 2024-T4 alloy is superior if the plate is undermatching; the 7075-T6 alloy is superior if the plate is overmatching.** For matching*** targets the 7075-T6 plate is superior at obliquities less than 60°; the 2024-T4 is superior for obliquities greater than 60°.

20 mm AP M95 and 20 mm AP T33 Projectiles
vs
2024-T4 Alloy

For the majority of target conditions investigated, the T33 projectile is more effective than the M95 projectile in defeating 2024-T4 plate (Figure 4). However, for intermediate plate thicknesses at high obliquity, the M95 is considerably superior (50 per cent on an energy basis for 1-inch plate at 60° obliquity).

*Undermatching plate - thickness is less than projectile diameter.

**Overmatching plate - thickness is greater than projectile diameter.

***Matching plate - thickness is equal to projectile diameter.

20 mm AP M95 and 20 mm AP T33 Projectiles
vs
7075-T6 Alloy

Under all conditions of attack the AP T33 projectile is equal or superior to the 20 mm AP M95 projectile in defeating 7075-T6 alloy (Figure 5). Against one target of 1-inch plate at 65° obliquity, the M95 projectile required about one per cent less limit energy than the T33, but this is not significant. The M95 projectile requires as much as 65 per cent more limit energy to defeat 1/2-inch plate at 65° obliquity than is needed by the T33 projectile.

Spalling

Figures 6 to 11, incl, are photographs of the front and back surfaces of 1/2 and 1 1/2 inch thick 2024-T4 and 7075-T6 aluminum alloy plates after being subjected to 20 mm projectile firing. In Figure 6 (A and B), rounds 1 to 4 are 20 mm AP T33 projectile impacts and rounds 5 to 11 are 20 mm AP M95 projectile impacts, all at 60° obliquity. In Figure 7 (A and B), rounds 1 to 6 are 20 mm AP T33 projectile impacts and rounds 7 to 12 are 20 mm AP M95 projectile impacts. It may be noted that the projectile impacts on the front surfaces of the 2024-T4 and 7075-T6 plates are similar in appearance. However, the rear surfaces show considerable spalling for the 7075-T6 alloy, while the 2024-T4 plate shows practically no spalling. Figure 7B shows spalling for rounds 3, 5, 8, and 9, even though the projectiles only partially penetrated the plate.

Figures 8B and 9B show that 7075-T6 alloy spalls considerably more on the rear than 2024-T4 alloy for 1 1/2 inch thicknesses. Rounds 1 to 5 on Figure 8 (A and B) and rounds 1 to 7 on Figure 9 (A and B) represent 20 mm AP T33 projectile impacts at 60° obliquity.

Figures 10 (A and B) and 11 (A and B) show caliber .50 AP M2 projectile impacts on 1/4 inch thick 2024-T4 and 7075-T6 alloy plates set at 80° obliquity. It may be noted in Figure 10B that very little material is ejected from the rear of the 2024-T4 plate even though rather large projectile holes were produced withouth going through (note rounds 2 and 4 of Figure 10B). In contrast, the 7075-T6 plate, which had a similar ballistic limit, 2650 fps (Table I), spalled considerably more (Figure 11B).

CONCLUSIONS

1. The 2024-T4 aluminum alloy is generally superior to the 7075-T6 alloy with respect to ballistic protection, and spalls considerably less.

2. On the whole, the 20 mm AP T33 projectile is superior to the 20 mm AP M95 projectile for defeating aluminum alloy plates of these two types.

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3. W. M. Baldwin, Jr., L. J. Ebert, M. L. Fried, and R. P. Frohmberg, "The Properties of Heavy Gage Aluminum Alloys for Armor," Case Institute of Technology Final Report on Contract W33-019-ORD-6061, March 1950.

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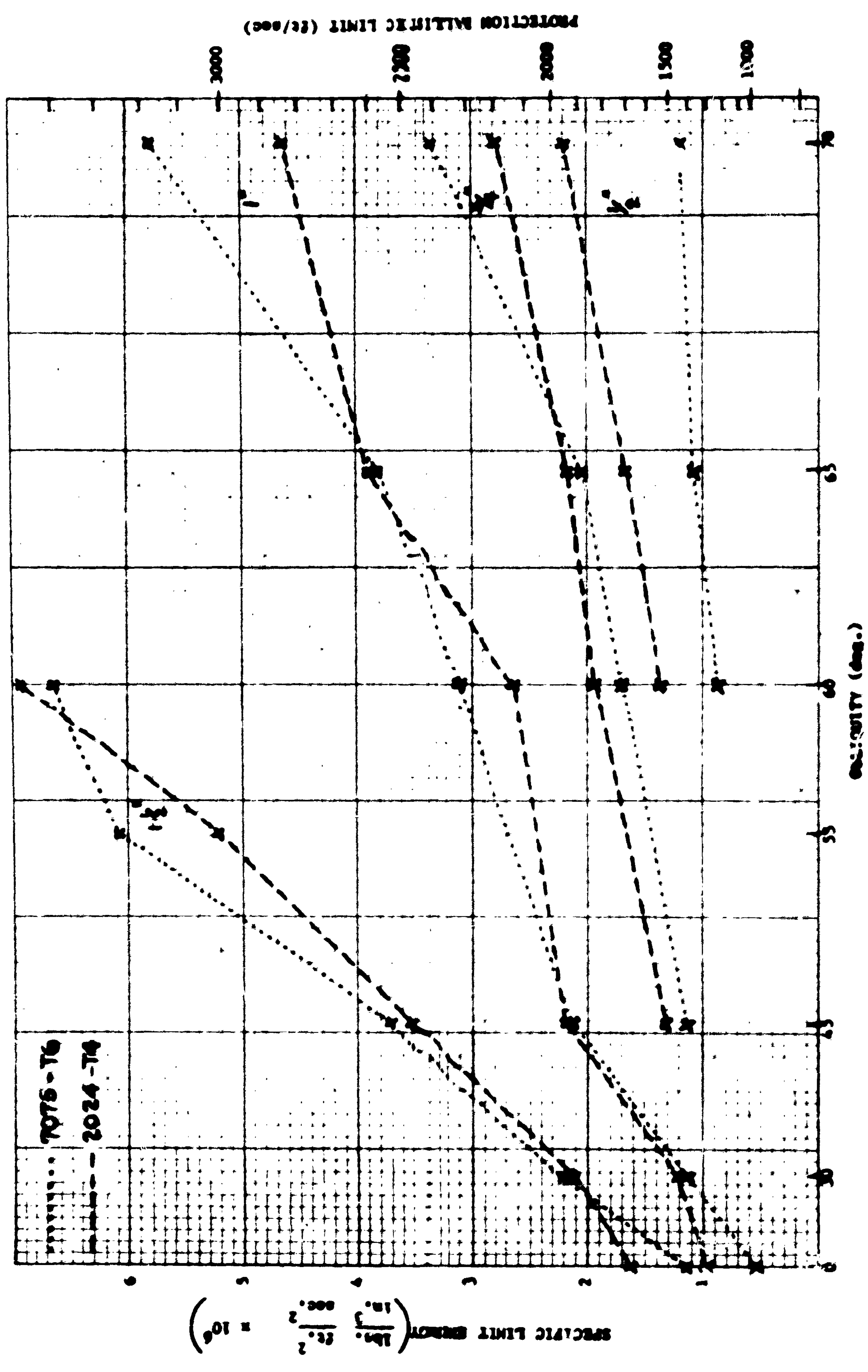

Figure 1. Ballistic resistance of 2024-T4 and 7075-T6 aluminum alloy plate vs 20 mm AP M95 projectiles

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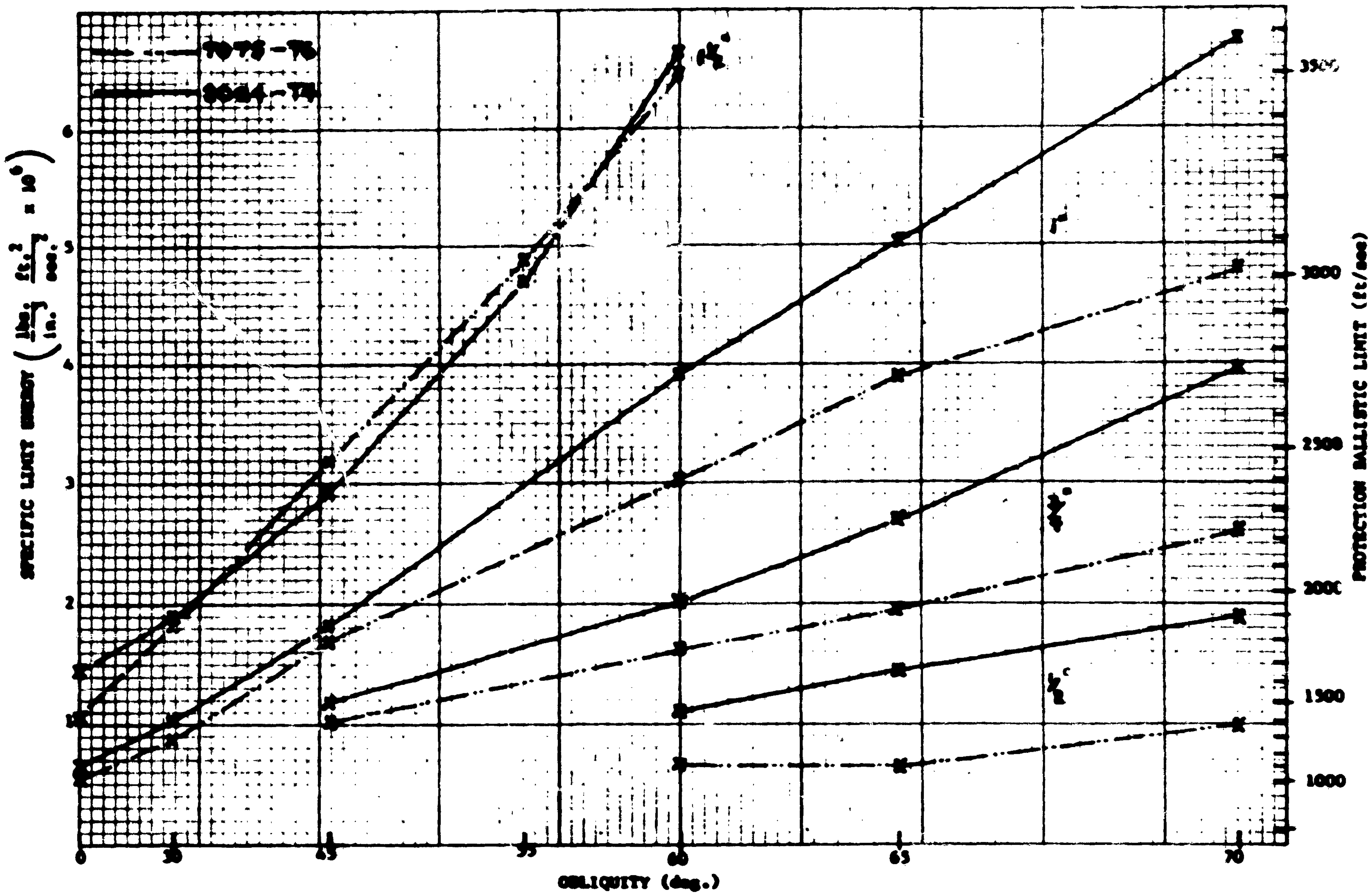

Figure 2. Ballistic resistance of 2024-T4 and 7075-T6 aluminum alloy plate vs 20 mm AP T33 projectiles

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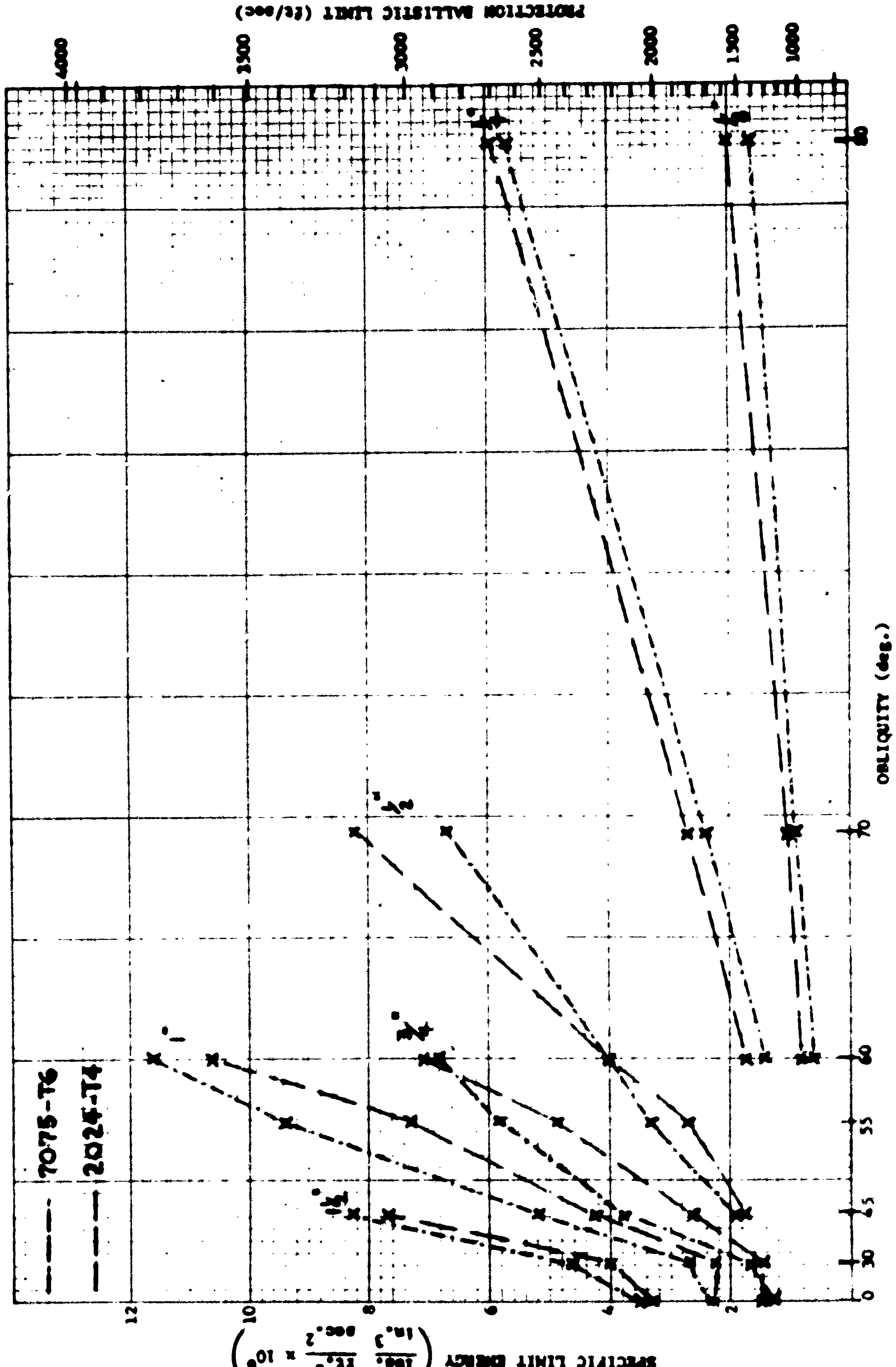

Figure 3. Ballistic resistance of 2024-T4 and 7075-T6 aluminum alloy plate vs caliber .50 AP M2 projectiles

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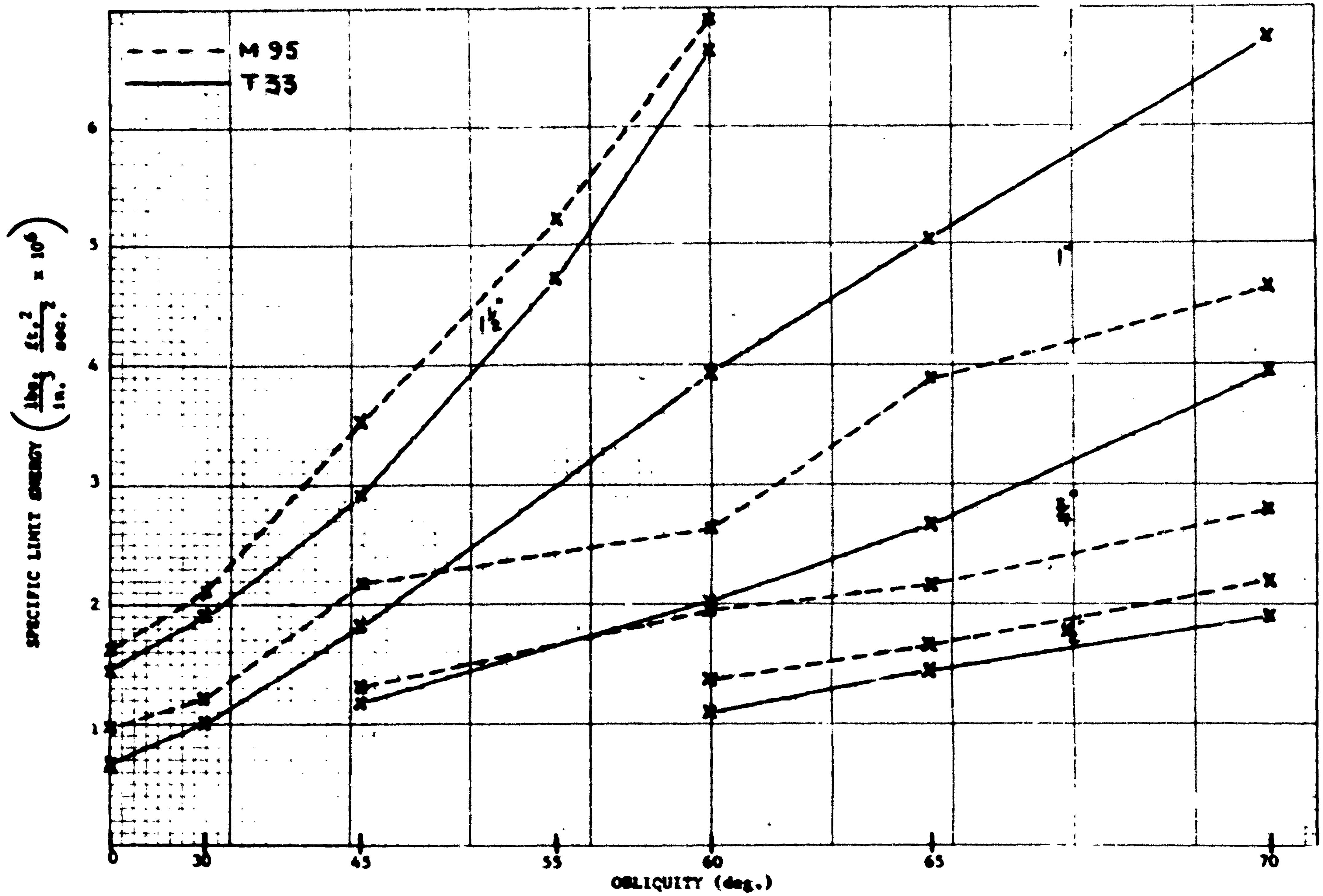

Figure 4. Ballistic performance of 20 mm AP M95 and AP T33 projectiles vs 2024-T4 aluminum alloy plate

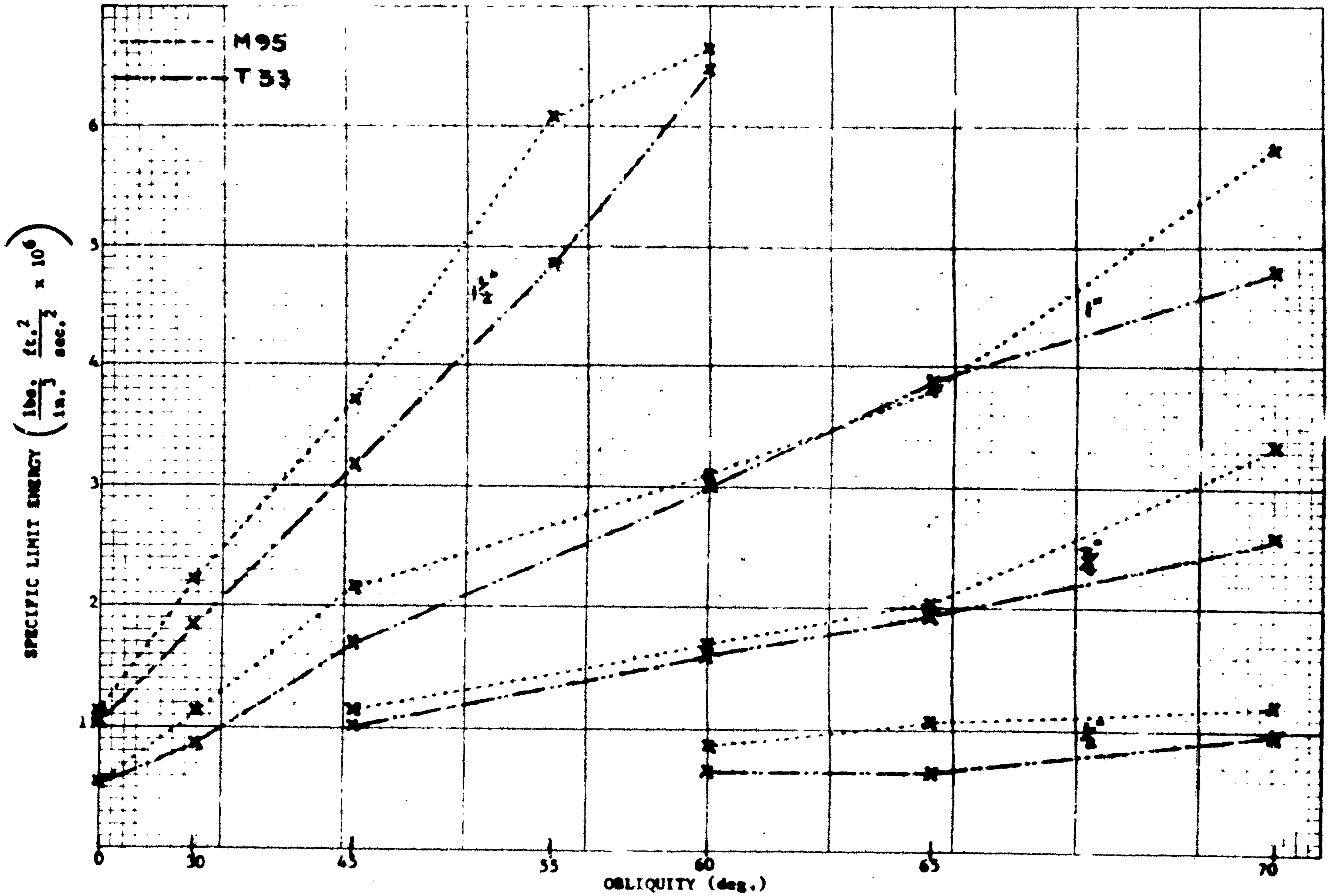

Figure 5. Ballistic performance of 20 mm AP M95 and AP T33 projectiles vs 7075-T6 aluminum alloy plate

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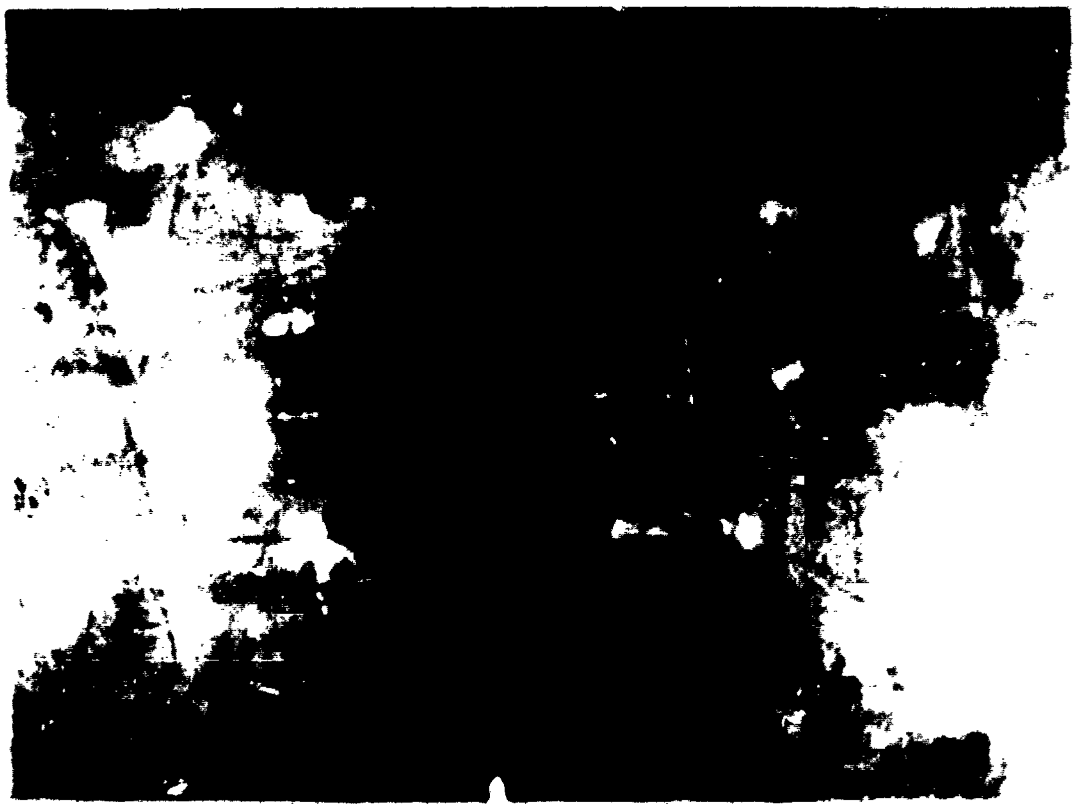
A



B

Figure 6. 20 mm projectile impacts on 1/2 inch 2024-T4 aluminum alloy plate

A - Front surface B - Rear surface

(Rounds 1 to 4 (AP T33) and rounds 5 to 11 (AP M95) at 60° obliquity; rounds 12 to 15 (AP T33) and rounds 16 to 19 (AP M95) at 70° obliquity)

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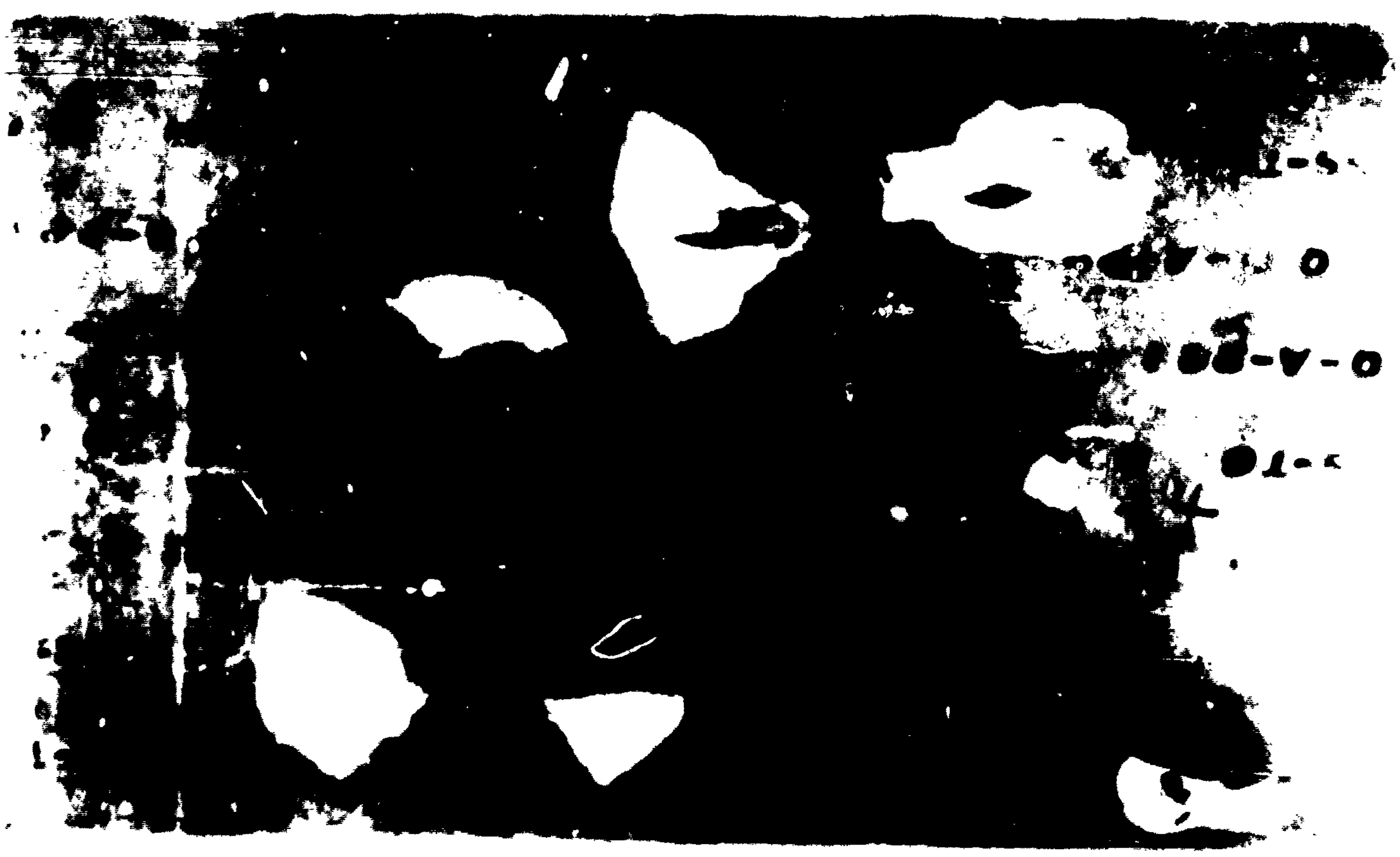
A



B

Figure 7. 20 mm projectile impacts on 1/2 inch 7075-T6 aluminum alloy plate

A - Front surface B - Rear surface

(Rounds 1 to 6 (AP T33) and rounds 7 to 12 (AP M95) at 60° obliquity)

Neg. #34815
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Figure 8. 20 mm projectile impacts on 1 1/2 inch 2024-T4 aluminum alloy plate

A - Front surface B - Rear surface

(Rounds 1 to 5 (AP T33) at 60° obliquity; rounds 6, 7, 8, 9, and 18 (AP T33) and 10 to 17 (AP M95) at 0° obliquity)

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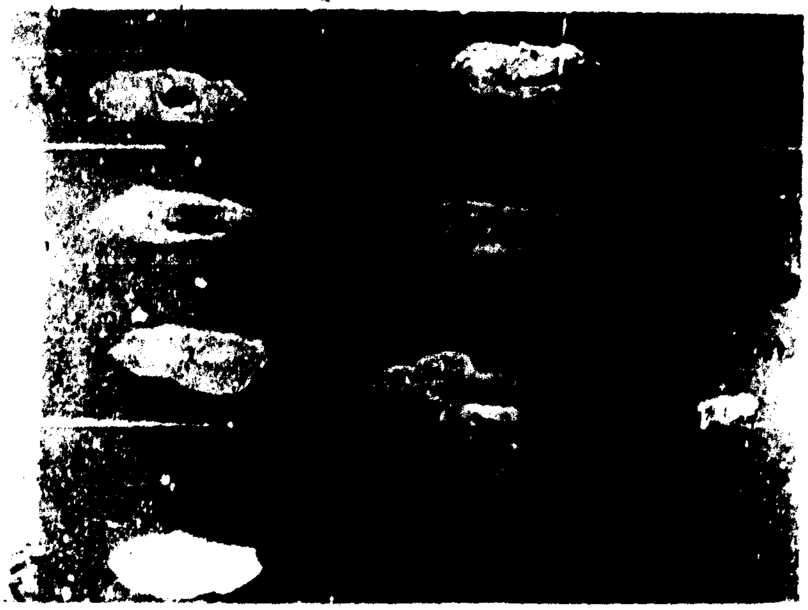
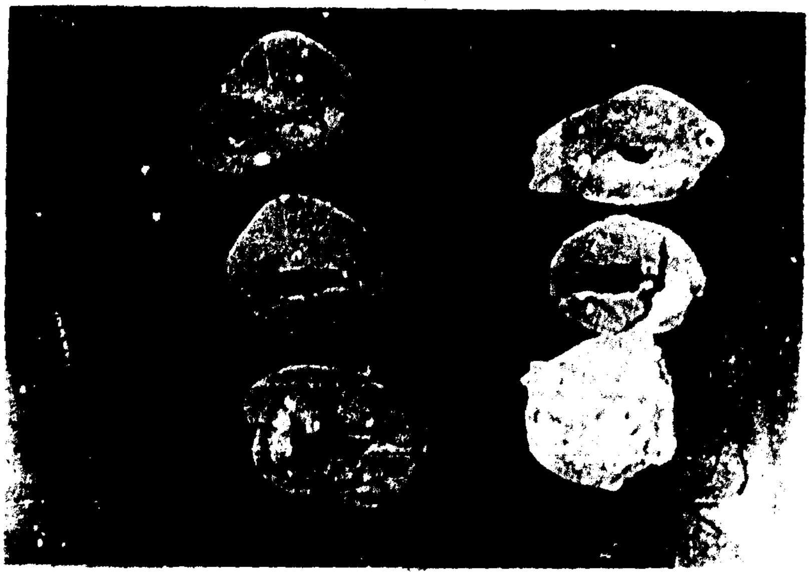
R-1395



A



B

Figure 9. 20 mm AP T33 projectile impacts on 1 1/2 inch 7075-T6 aluminum alloy plate at 60° obliquity

A - Front surface   B - Rear surface

A

Figure 10. Caliber .50 AP M2 projectile impacts on 1/4 inch 2024-T4 aluminum alloy plate at 80° Obliquity

A - Front surface B - Rear surface

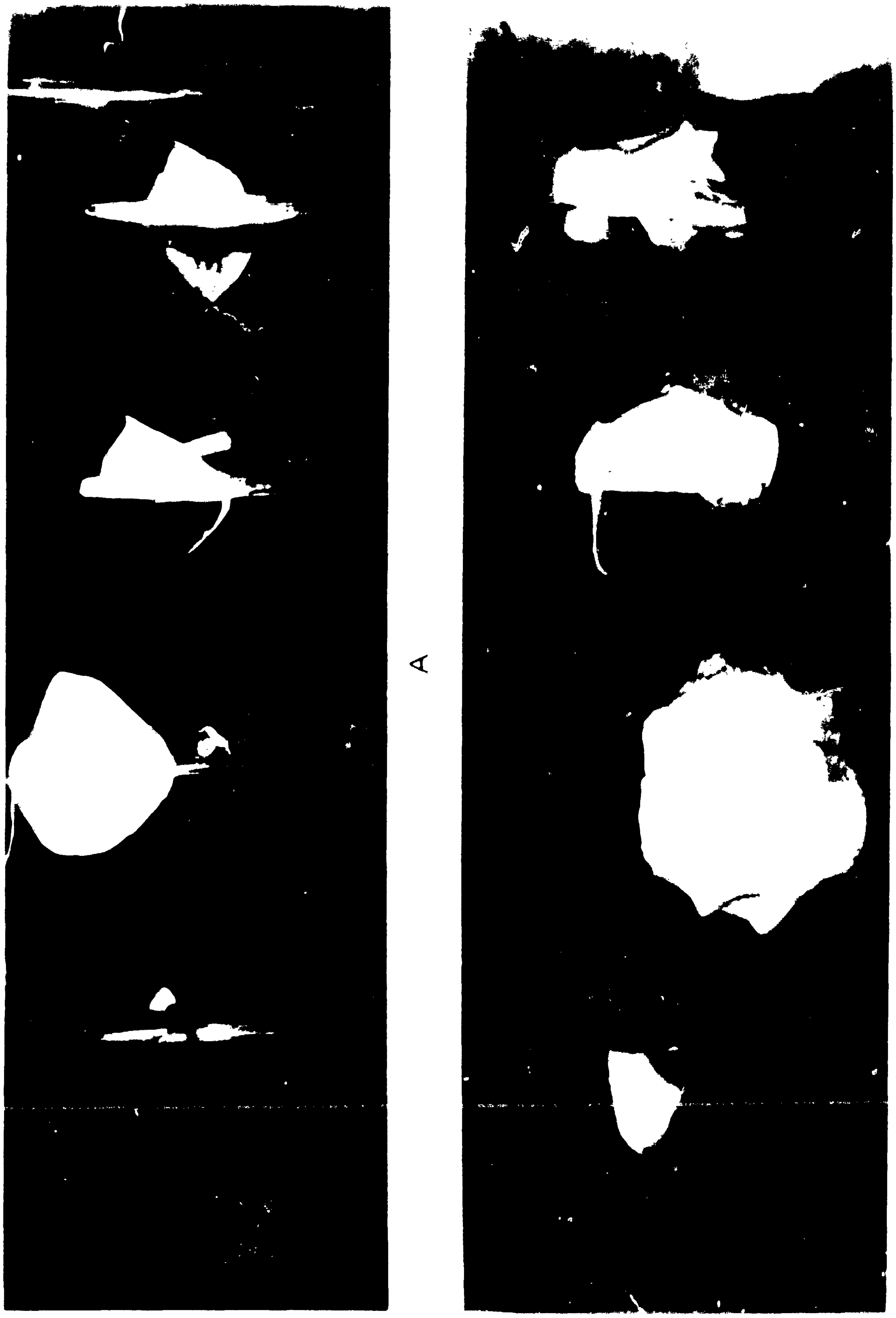


Figure 11. Caliber .50 AM M2 projectile impacts on 1/4 inch 7075-T6 aluminum alloy plate at 80° obliquity

A - Front surface B - Rear surface

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